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Of overarching concern is the growth in human populations and consumption. Accordingly, the physical condition of the world is deteriorating rapidly. The Global Footprint Network (www.footprintnetwork.org) estimates that we are using approximately 164% of the world's sustainable productivity now, up from 70% in 1970. Consequently, higher estimates of future extinction, say, within this century, appear warranted than those based on current conditions. The highest estimates of threat (up to 60%) come from assuming that all species endemic to a country may be at risk because of their presumed small ranges and on-going habitat loss [11], as the conditions just enumerated accelerate. All in all, it seems reasonable to assume that half of all species, most of them unknown at the time of their loss, may disappear within the remainder of this century.

For plants, unlike most other groups of organisms, *ex situ* preservation is relatively simple [12]. Seed samples gathered from maternal parents, say 20 from a population, will reasonably represent the genetic diversity of the population. With cryopreservation and other special techniques available, practically any plant can be preserved in a seed bank for decades or more. Another option is tissue culture. Plants can of course also be maintained in cultivation, even though it is difficult to maintain sufficient genetic diversity to support a species or even a population that way.

To save them in any way means that we must know that they exist. Given the essential value that plants have for human life, it is clearly well worth finding ways to push as hard as we can to discover missing species and preserve them. For some, it may be their last days in nature.

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References

1. Royal Botanic Gardens, Kew (2016) *The State of the World's Plants, 2016,* Royal Botanic Gardens, (Kew)
2. Pimm, S.L. *et al.* (2014) The biodiversity of species and their rates of extinction, distribution, and protection. *Science* 344, 1246752
3. Pimm, S.L. and Joppa, L.N. (2015) How many plant species are there, where are they, and at what rate are they going extinct? *Annals of the Missouri Bot. Garden* 100, 170–176
4. Joppa, L.N. *et al.* (2011) How many species of flowering plants are there? *Proc. Biol. Sci.* 278, 554–559
5. Sodhi, N.S. *et al.* (2013) *Conservation Biology: Voices from the Tropics,* Wiley Blackwell
6. Brummitt, N.A. *et al.* (2015) Green plants in the red: a baseline global assessment for the IUCN sampled Red List Index for plants. *PLoS ONE* 10, e0135152
7. Bebber, D.P. *et al.* (2010) Herbaria are a major frontier for species discovery. *Proc. Nat. Acad. Sci.* 107, 22169–22171
8. De Vos, J.M. *et al.* (2015) Estimating the normal background rate of species extinction. *Conserv. Biol.* 29, 452–462
9. Urban, M.C. (2015) Accelerating extinction risk from climate change. *Science* 348, 571–573
10. Pereira, H.M. *et al.* (2010) Scenarios for global biodiversity in the 21st century. *Science* 330, 1496–1501
11. Pitman, N.C. and Jørgensen, P.M. (2002) Estimating the size of the world's threatened flora. *Science* 298, 989–989
12. Walters, C. *et al.* (2013) Preservation of recalcitrant seeds. *Science* 339, 915–916
13. Lyon, S.P. (2016) Six new species of New Guinea *Corybas*. *Malaysian Orchid J.* 18, 85–103

Forum

Does Biodiversity–Ecosystem Function Literature Neglect Tropical Ecosystems?

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Current evidence suggests that there is a positive relationship between biodiversity and ecosystem functioning, but few studies have addressed tropical ecosystems where the highest levels of biodiversity occur. We develop two hypotheses for the implications of generalizing from temperate studies to tropical ecosystems, and discuss the need for more tropical research.

Biodiversity Concerns

Recently, species loss has inspired a vast number of studies attempting to describe links between biodiversity and ecosystem function (BEF) [1]. Consequently, this research has, in general, found positive effects of biodiversity on ecosystem functions [1] and their resilience [2]. However, there is an unmistakable bias in BEF study locations, with a noticeable lack of experiments occurring within the tropics, where communities are generally more diverse [3] and at higher risk of extinction than are communities in temperate regions [4]. We discuss here this experimental bias and consider how, if at all, BEF relationships can be extrapolated from theory developed from temperate experiments.

A Temperate Bias

Across both terrestrial and aquatic studies, experiments in temperate regions of the world dominate the literature. To quantify this bias, we considered 182 BEF studies (47 marine, 110 terrestrial, 25 freshwater) taken from four meta-analyses exploring different aspects of the biodiversity–ecosystem function relationship, including effects on primary productivity across ecosystems, predation rates, production, consumption or biogeochemical fluxes in marine systems, and tree productivity in forestry plantations (Table S1 in the supplemental information online gives a list of meta-analyses and studies). Of these studies, only 13% (24 studies) were carried out in the tropics (±23.5° latitude, Figure 1). In addition, specific regions within the temperate zone dominate experimental locations, with the majority of temperate studies being within the USA and NW Europe (Figure 1). The same observation can be made for the tropical studies, where 42% (10 studies) were conducted in Costa Rica (Figure 1). This raises the

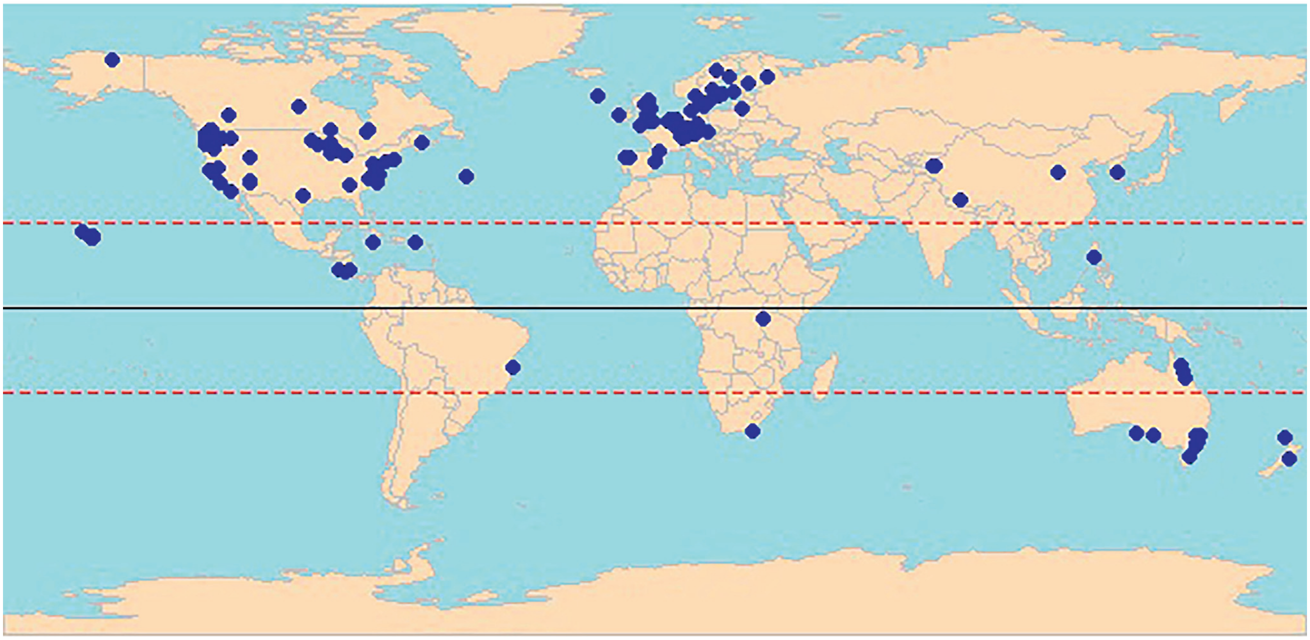

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Figure 1. World Map Showing the Locations (Blue Circles) of Biodiversity and Ecosystem Function (BEF) Experiments Taken from Four Meta-Analyses That Explored Different Aspects of the Biodiversity–Ecosystem Function Relationship. The meta-analyses are summarized in Table S1. The solid black line is the equator and the red dashed lines represent the tropics of Cancer and Capricorn.

question of how tropical regions, which harbor the greatest amounts of biodiversity [3], will respond to biodiversity declines.

Tropical Biodiversity and Logistic Difficulties

Both terrestrial and aquatic tropical ecosystems are characterized by disproportionately higher levels of plant and animal diversity relative to their temperate counterparts [3,5]. For example, of the designated 25 biodiversity 'hotspots' across the globe, 16 occur in the tropics, and the predominant habitat type, tropical forests, features in 15 of the 16 tropical hotspots [5]. Furthermore, anthropogenic disturbances have led to dramatic declines in the diversity and habitat complexity of tropical ecosystems [6]. Another research void occurs in tropical marine systems, despite the fact that tropical coral reefs, for example, are one of the most biologically diverse ecosystems on the planet, and are sites of high endemism [7].

Conducting BEF studies in the tropics can be logistically difficult because of the large number of species and the high structural complexity of communities such as tropical forests and coral reefs that need to be replicated in experiments. In addition, much of the tropics are associated with inadequate funding, leading to less money spent on biodiversity research [8]. The top five most important countries, in terms of the amount of endemic plants and animals they contain, are responsible for only 1.6% of publications on the topic [8]. To focus experimental efforts, therefore, it is worthwhile to evaluate the applicability of theory developed from temperate studies to the development of useable hypotheses for tropical systems.

What Can Temperate BEF Studies Teach Us about Tropical Diversity Loss?

Ecosystem function generally follows a saturating function of species richness, with ecosystem function approaching a maximum for high species richness [1]. Thus, the effects of species loss or gain on ecosystem function depend on where species richness falls along the spectrum. When species richness is high, we may not find large effects of species loss on ecosystem function, but species loss at relatively low levels of richness can lead to dramatic reductions in function. This negligible effect of species loss at high species richness may be explained by niche redundancy. Indeed, niche, or resource, partitioning has long been a proposed mechanism responsible for the positive relationship between biodiversity and ecosystem function [1].

Because tropical systems generally have higher levels of species richness [3], we can develop two hypotheses from which to extrapolate temperate BEF studies to tropical systems. First, if we assume the relationship between biodiversity and ecosystem function is similar in temperate and tropical ecosystems, we can use the curve developed from temperate systems

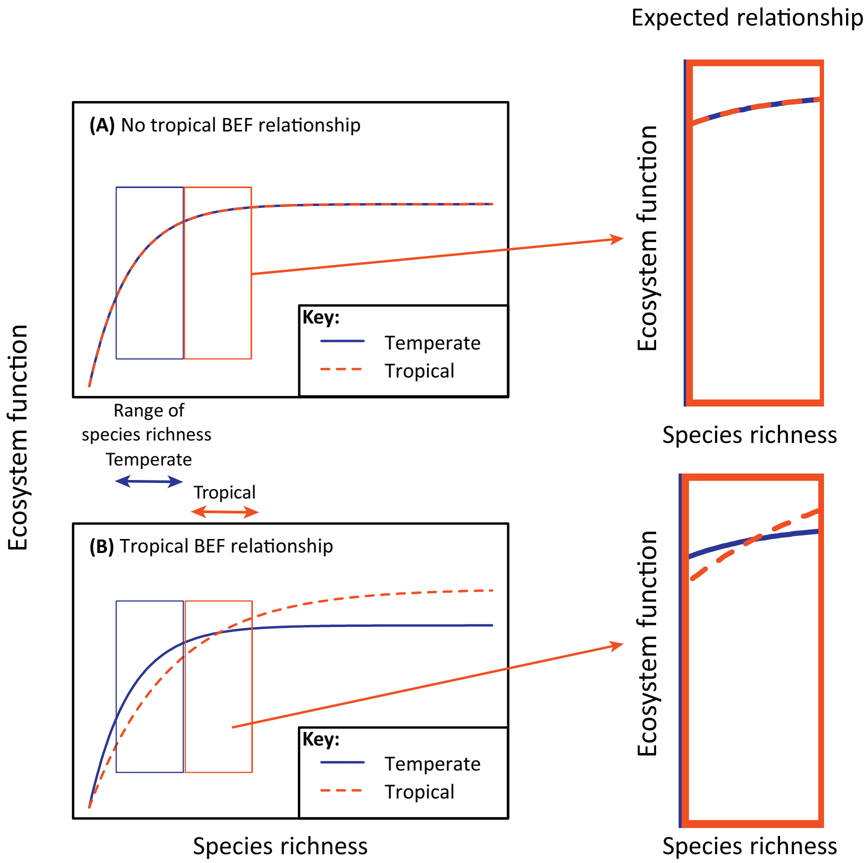

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Figure 2. Conceptual Diagram Depicting the Hypothetical Difference between Temperate and Tropical Systems. (A) There is little effect of the additional biodiversity found in the tropics and the biodiversity and ecosystem function (BEF) relationship is the same for both systems. (B) Increased heterogeneity creates more niche opportunities within the tropics and allows a more diverse range of organisms to exploit these resources. Therefore, it takes longer for these niches to be filled, which results in a saturation point that is higher than that of temperate systems.

to predict changes in species richness for tropical systems. In this case, tropical systems may occur above the saturation point, and variations in species richness may only weakly effect ecosystem function. To demonstrate this, we present a curve inspired by real data that describes a hypothetical relationship between biodiversity and ecosystem function [1] (Figure 2A). The second scenario occurs in tropical systems in which the saturation point (when adding species no longer has an effect on ecosystem function) occurs at higher values of species richness than in their temperate counterparts. In this scenario, species loss in the more speciose tropical regions may still have large effects on ecosystem function (Figure 2B). This then begs the question of why the saturation point would differ between temperate and tropical systems. One potential mechanism that could increase the saturation point is tighter niche packing as a result of greater specialization. Because ecological specialization has been found to increase towards the tropics [9], one could argue that the effects of biodiversity on ecosystem function are likely to differ between tropical and temperate systems as a consequence.

We propose two hypotheses about biodiversity–ecosystem function relationships in the tropics. Hypothesis 1: tropical systems are the same as temperate systems, in which case the loss of the additional diversity found in the tropics will have less effect on ecosystem function than in temperate systems (Figure 2A). Hypothesis 2: increased niche partitioning in the tropics results in a stronger BEF relationship, and more species are therefore necessary to maintain ecosystem function (Figure 2B). To understand whether maintaining tropical biodiversity is important for ecosystem function, these hypotheses need to be evaluated empirically.

The most straightforward approach is to conduct more BEF studies in the tropics, using methodologies established in temperate studies. However, logistic limitations often lead to low levels of species richness and environmental variability in temperate experiments, and this experimental challenge may be magnified in the tropics, which are characterized by high levels of diversity and environmental complexity. Therefore, correlative studies across temperate and tropical environments may help to elucidate latitudinal trends in BEF relationships. For example, an analysis of global fish surveys [10] quantified biodiversity effects, among other predictors, on fish biomass. They found that, as species richness increased, fish biomass increased, but the effect of richness was less pronounced in the tropics. This relationship supports hypothesis 1. Similarly, evaluating specialization across environmental gradients or combining theoretical models with experimental data across latitudinal gradients may lead to a better understanding of niche overlap in different geographical regions [11]. As in temperate zones, anthropogenic stressors such as hunting and overfishing are prominent in the tropics [6]. Therefore, given the roles these stressors play in the reduction of biodiversity, experiments must be considered in light of realistic diversity loss [12].

Concluding Remarks

There is a crucial need to increase investment and focus on BEF research in tropical systems. These regions contain high levels of biodiversity which are facing rapid declines as a result of anthropogenic disturbances. In addition, existing BEF theory developed from temperate systems may not apply to the tropics. Increasing this knowledge is crucial for improving conservation efforts to promote ecosystem function in the presence of anthropogenic stressors.

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Appendix A Supplemental Information

Supplemental information associated with this article can be found online at http://dx.doi.org/10.1016/j.tree.2017.02.012.

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References

1. Tilman, D. *et al.* (2014) Biodiversity and ecosystem functioning. *Annu. Rev. Ecol. Evol.* 45, 471–493
2. Oliver, T.H. *et al.* (2015) Biodiversity and resilience of ecosystem functions. *Trends. Ecol. Evol.* 30, 673–684
3. Brown, J.H. (2014) Why are there so many species in the tropics? *J. Biogeogr.* 41, 8–22
4. Finnegan, S. *et al.* (2015) Paleontological baselines for evaluating extinction risk in the modern oceans. *Science* 348, 567–570
5. Myers, N. *et al.* (2000) Biodiversity hotspots for conservation priorities. *Nature* 403, 853–858
6. Bradshaw, C.J. *et al.* (2009) Tropical turmoil: a biodiversity tragedy in progress. *Front. Ecol. Environ.* 7, 79–87
7. Roberts, C.M. *et al.* (2002) Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science* 295, 1280–1284
8. Wilson, K.A. *et al.* (2016) Conservation research is not happening where it is most needed. *PLoS Biol.* 14, e1002413
9. Dyer, L.A. *et al.* (2007) Host specificity of Lepidoptera in tropical and temperate forests. *Nature* 448, 696–699
10. Duffy, J.E. *et al.* (2016) Biodiversity enhances reef fish biomass and resistance to climate change. *Proc. Natl. Acad. Sci. U. S. A.* 113, 6230–6235
11. Northfield, T.D. *et al.* (2010) Niche saturation reveals resource partitioning among consumers. *Ecol. Lett.* 13, 338–348
12. Naeem, S. (2008) Advancing realism in biodiversity research. *Trends. Ecol. Evol.* 23, 414–416